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DISCLAIMER

LASER-BASED PROFILE AND ENERGY MONITOR FOR H⁻ BEAMS*

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Abstract

A beam profile and energy monitor for H^- beams based on laser photoneutralization was built at Brookhaven National Laboratory (BNL)* for use on the High Intensity Neutrino Source (HINS) at Fermilab. An H^- ion has a first ionization potential of 0.75eV and can be neutralized by light from a Nd:YAG laser (λ=1064nm). To measure beam profiles, a narrow laser beam is stepped across the ion beam, removing electrons from the portion of the H^- beam intercepted by the laser. These electrons are channeled into a Faraday cup by a curved axial magnetic field. To measure the energy distribution of the electrons, the laser position is fixed and the voltage on a screen in front of the Faraday cup is raised in small steps. We present a model which reproduces the measured energy spectrum from calculated beam energy and space-charge fields. Measurements are reported from experiments in the BNL linac MEBT at 750keV.

INTRODUCTION

In 2002 we reported on a project at BNL to develop a beam profile monitor for H^- beams using photoneutralization by a laser beam directed perpendicular to the ion beam [1]. That effort was in support of the Spallation Neutron Source being built at Oak Ridge National Lab [2]. Recently BNL was contracted by Fermi National Lab to build a laser-based H^- beam-profile monitor for use on the HINS [3].

A pulse of electrons is removed from an H^- beam by directing a 50mJ, 10ns light pulse from a Q-switched Nd:YAG laser through the ion beam. This electron pulse is channeled into a Faraday cup via a curved axial magnetic field produced by a series of coils. To measure transverse profiles, the trajectory of the focused laser beam is moved across the ion beam in small steps by small rotations of a mirror about 45°. At each mirror angle the electron current is integrated over the full laser pulse. A profile is produced by plotting total charge vs. mirror position.

In addition to transverse ion-beam profiles we measure the energy distribution of the signal electrons by ramping the voltage on a retarding grid in front of the cup. The energy of each electron is the sum of the initial kinetic energy and the energy it receives from the space-charge field as it is transported to the collector [4].

* This work was performed under the auspices of the U.S. Department of Energy.

In this paper we describe the detector and the measurements. We present a model which reproduces the measured energy spectrum from the beam current and transverse size, bunch length, and bunching fraction of the H- beam. The energy measurements are motivated by the desire to measure the energy spread of the H^- beam. For the test beam energy of 750keV beam energy-spread information is buried in the space-charge effects, but we anticipate being able to measure beam energy spread in the BNL HEBT at 200MeV based on these experiments.

DETECTOR

Figure 1 is a diagram of the detector from the side showing the signal-electron path. The neutralization chamber is a six-way cross with the laser beam passing through viewports either horizontally or vertically. A curved solenoidal magnetic field, generated by a series of coils, channels the signal electrons into the Faraday cup collector. A voltage grid in front of the collector provides secondary-electron suppression for profile scans and retarding voltage for energy scans. The Faraday cup charge signal passes to ground through a 1kΩ resistor. The resulting voltage pulse is digitized by a LeCroy LT584L oscilloscope.

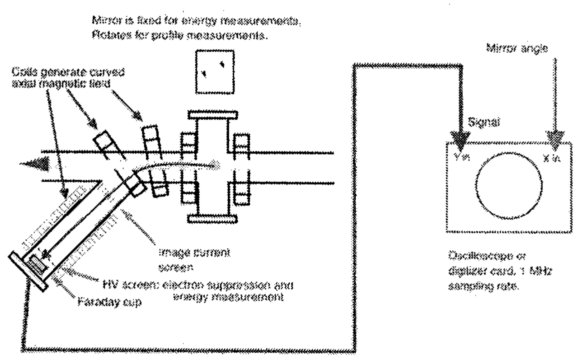

Figure 1: Longitudinal schematic. Electrons from the H^- beam are guided by magnetic field through grid into cup.

A transverse diagram of the device is shown in fig. 2. The 50mJ/pulse laser head [5] is mounted on an optics plate with a linear translation stage [6] to select scanning axis and two galvo-motors [7] to rotate mirrors about 45° to scan the laser beam. The optics platform and the full beamline installation in shown in fig. 3.

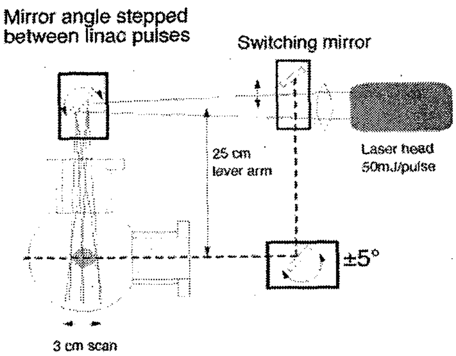

Figure 2: Transverse optical system

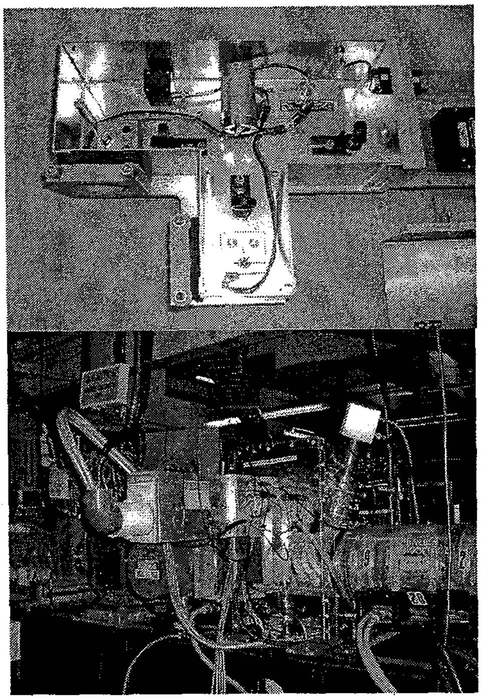

Figure 3: Optics platform (top) showing laser head at right and axis-switching actuator at top center. In beamline installation the ion beam travels left to right. The electron collector is top right. Field coils are right of center around the beamline.

The control system is a Labview program running on a dedicated PC with digital and analog I/O through a National Instruments USB-6229 BNC. The maximum firing rate of the laser is 20Hz so only one data point can be obtained per linac cycle (6.6Hz). A measurement cycle is initiated by a timing pulse from the linac which triggers the laser. The laser outputs a Q-switch synchronous pulse which triggers the scope. The signal pulse from the Faraday cup is passed through a 10MHz low-pass filter into the scope which does a baseline subtraction and integrates the pulse. Upon completion of this process, the scope signals the computer which reads the pulse.

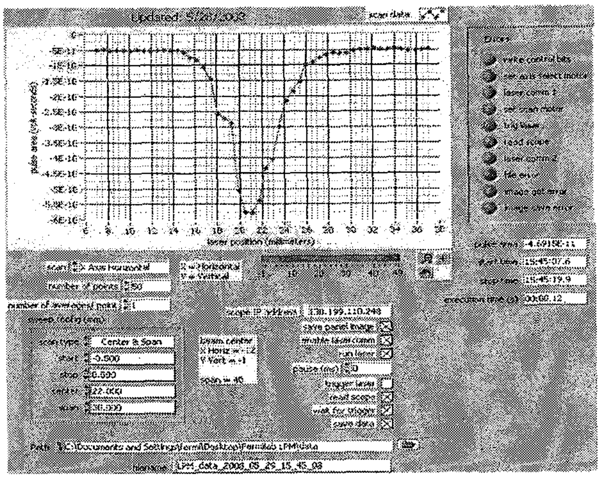

Figure 4: The Labview page showing a profile measurement

MEASUREMENTS

The laser-pulse length is about 10ns at the base and the ion-beam bunches are 5ns apart. It is not possible to lock the laser pulse to the rf structure of the beam so the laser timing is random with respect to the beam rf buckets. To compensate for the timing jitter a profile is built up by accumulating several pulses at each of several mirror angles. Figure 4 shows a profile taken with one measurement at each mirror position. The shot-shot jitter is evident in the jagged pulse edges. Averaging smoothes the edges.

An electron-energy spectrum is accumulated by keeping the mirror stationary and incrementing the voltage on the retarding grid. A signal electron is born with a kinetic energy of $T_{e0}= T_{H-}(m_e/M_H)=750{,}000/1838=408$eV, where m_e and M_{H-} are the masses of electron and H- ion respectively. As it is transported out of the beam along the magnetic field lines its energy is modified by the space-charge field.

A newly detached electron is moving with the H^- beam. Electrons born in front of the bunch will experience an electrostatic force in the forward direction while the electrons born in back of the bunch will feel a force in the backward direction. Therefore the total energy of an electron born in the front of a beam bunch is $T_{e0}+\varphi$ and one in back of the bunch is $T_{e0}-\varphi$, where φ is the space charge potential due to H- beam, fig. 5.

This detector was located about 5m down stream from the RFQ. There are two buncher cavities in this space. PARMILA simulations show that for 70 mA beam, at this location about 50% of the beam is de-bunched due to space charge with the bunchers on and is debunched with them off. This 50% unbunched beam results in beam loss in DTL Tank1.

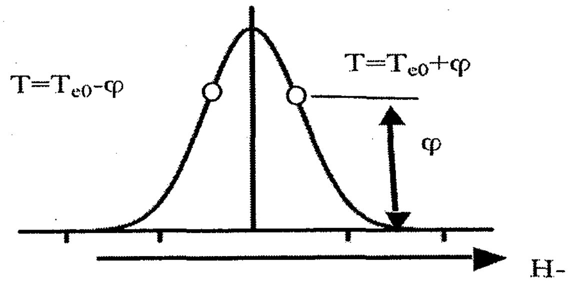

Figure 5: Illustration showing space-charge model used in simulation. Electrons in back of bunch lose the space-charge potential, φ, and those in front gain φ.

Figure 6 shows measured energy spectra from an unbunched beam and 35mA and 70mA bunched beams. The spectrum from the unbunched beam has a low-energy cutoff of 408eV and a high-energy cutoff of 600eV. The calculated space-charge potential on the axis of the unbunched beam is -200V.

The electrons from the bunched beams are born with 408eV and gain or lose energy from the space-charge potential. The low-energy of detected electrons should extend to near zero. However for all bunched-beam spectra the low-energy cutoff is about 250eV which is the time-of-flight cutoff from the integration window.

The high-energy cutoff is the initial kinetic energy plus the maximum space-charge potential in the bunch. For the 50% bunched 70mA beam the calculated potential at bunch center is -750V giving a calculated maximum electron energy of 1150eV. We measured 1025-1100eV. The 70%-bunched, 35mA beam gave a calculated maximum energy of 850eV and we measured 825eV. Also measured, but not on fig. 6, was a 17mA beam producing a maximum electron energy of 700eV.

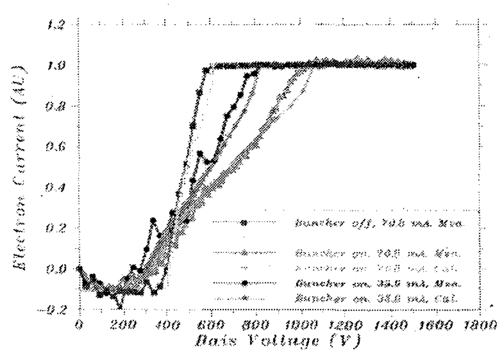

Figure 6: Electron current vs. screen voltage for buncher off and 35mA and 70mA with buncher on. Here the electron current is negative, zero is the top flat line.

Also shown on fig. 6 are calculated energy spectra from the three beam models given in Table I. The calculation models the beam as 3D Gaussian bunches with the transverse dimensions we measured and the longitudinal dimension as calculated by PARMILA riding on top of a DC beam.

Table I: Beam parameters used in the calculations

Current mA	Buncher On/off	% of DC component	Bunched Length degrees
70	OFF	100	360
70	ON	50	90
35	ON	30	70

DISCUSSION

This detector provides accurate transverse profile measurements of an H^- beam together with the energy spectrum of the signal electrons. At the low energy of this experiment an electrostatic model was used to fit the energy spectrum data. Using the measured beam current and transverse size, the bunch length and bunching fraction can be deduced. Extrapolation of these results indicates this method can be used to measure beam energy spread to 0.1% in the 200MeV HEBT.

The detector described here and the ones in refs. 1 and 2 use pulsed Nd:YAG lasers which allow one data point to be taken on each linac cycle. In a modern clean vacuum environment it should be possible to use a fiber-coupled diode laser with microchannel-plate (MCP) amplification to produce a profile with a 200μs scan of a single linac cycle [8]. This was our original design and the Faraday cup was a MCP detector with all surfaces connected in parallel. At the location of this experiment the gas-stripping signal [9] saturated the MCP.

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REFERENCES

[1] R. Connolly *et. al.*, "Laser Beam-Profile Monitor Development at BNL for SNS," Proc. 2002 Linac Conf., Gyeongju.

[2] S. Assadi *et. al.*, "SNS Transverse and Longitudinal Laser Profile Monitors Design, Implementation and Results," EPAC 2006, Edinburgh.

[3] http://www-td.fnal.gov/projects/hins.html

[4] S. Lee *et. al.*, "Direct Measurements of Space-Charge-Potential in High Intensity H- Beam with Laser Based Photo Neutralization Method," Proc. DIPAC 2005, Lyon.

[5] http://www.quantel-laser.com/industrial-scientific-lasers/uk/fiche_produit.php#

[6] http://www.bluehilloptical.com/Galvoline.htm

[7] http://www.cambridgetechnology.com/

[8] R. Connolly *et. al.*, "Photodetachment Profile Monitor Proposal for H^- Beams at BNL," 11th ICFA Mini-Workshop on Diagnostics, SNS, Oak Ridge National Lab, 2002.

[9] R.E. Shafer, "Laser Diagnostic for High Current H- Beams", Proc. 1998 Beam Instrumentation Workshop (Stanford). A.I.P. Conf. Proceedings, (451), 191.